



DRIVING PRODUCTIVITY IN MANUFACTURING

Digital Transformation during Uncertain Times

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Management Summary

Most companies have invested significant time and resources in digitalization efforts. Today, the „low hanging fruits“ have largely been harvested. Usually, these are in the form of local process improvements, visualization of relevant KPI, or automation of information gathering and processing.

SHORTCUTS TAKEN EARLIER PREVENT LARGE-SCALE VALUE

Improvements have usually been locally visible but underwhelming on a company-wide scale. Based on our observations, this is mostly the result of six factors:

Bad quality of digitalized data, most frequently due to “media breaks” – steps in the information flow where data cannot be transferred fully automated.

To correct for experience-based factors like delays, absenteeism, and rework, an SAP-generated production schedule is manually levelled in an Excel sheet. Afterwards, it is not possible to track why certain changes have been made, or even which schedule was actually used at a given time.

Side processes, where the actual process does not fully follow the process in the relevant IT systems.

A manufacturing area uses paper forms to circumvent the available Manufacturing Execution System (MES): a special material flow needed for 1% of parts has not been implemented in the system. Even though input devices are available at all stations, the recorded data is only entered into the system at the end of the process.

Lack of leadership measures to ensure data quality, including management responsibility for data quality.

A faulty sensor constantly logs wrong processing times for some variants. The problem is known to shopfloor staff and fixed in an Excel sheet, however the wrong value is sent to the ERP. This causes calculations of manufacturing costs to be correct on average, but incorrect if analyzed per variant.

Heterogenous data, with no defined minimum information to be gathered in certain processes.

While new machines are fitted with IOT devices to collect basic information like status, piece counters etc., older machines have not been retrofitted – even though they will be used for several years more.

Lack of comparability or “contextualization” of collected data.

Production KPI cannot be filtered by individual produced products as the required information is not recorded.

Keeping unstable proof-of-concept solutions when they have served their purpose instead of stabilizing the software needed to run them.

Pilot IOT devices installed by a former employee on some machines for collecting data have been kept running long after the pilot has been closed. A different IOT vendor is used in most other devices. Nobody in the department still knows how to update the software on the pilot devices, and nobody dares to change configurations on them even though new information is needed.

CHALLENGING TIMES AND THE NEED FOR RESULTS

A challenging economic climate has recently led companies to prioritize immediate, hard savings over long-term initiatives.

This may lead to pausing or significantly reducing digitalization efforts for the moment. From our perspective this would be the wrong decision. Now is the time to question established ways which have led to the complexities slowing down digitalization in the first place, defining clear business goals to be driven by digitalization, and using digital tools to pursue direct benefits in suitable situations.

In recent years, many digital solutions and projects were introduced when demand was high, and capacities were fully utilized. For instance, new Manufacturing Execution System (MES) or digital KPI tracking systems were introduced

at fully utilized lines. In such a situation, stability is key, and major changes to established processes are dangerous: long-term benefits cannot outweigh immediate issues due to lost productivity in the short term.

Now there is a chance to review established solutions and simplify or stabilize evolved processes.

STREAMLINE, SIMPLIFY AND DIGITALIZE

This approach is supported by three activities: streamlining processes to the point where more automation is possible – not only physical automation, but also automation of information and knowledge work; uncovering waste in dynamic situations like changing variants and products; and freeing up time by throwing away island solutions binding many resources.

Challenge “the old ways”

Conduct a regular and systematic search for media breaks emerging for instance from Microsoft Excel sheets or self-built databases that are firmly integrated and used in existing processes. Regularly question exceptions and special handling to standard processes.

Ensure that area managers are responsible for the quality of data coming from their area of responsibility instead of being able to hide behind legacy systems or processes.



Leverage existing tools and competences

Empower your digitalization units to tackle entrenched habits, overly complex processes, and ingrained paradigms that obstruct digital transformation. Cross-functional teams of operational excellence and digitalization experts, backed by strong management commitment to streamline processes, work best.

Equip this team with tools for basic statistical data analysis on value stream data or digital lean methods to identify waste and uncover improvement opportunities in manufacturing processes.



Do not “reinvent the wheel” and remove burdens

Relying heavily on self-developed in-house solutions may seem cheaper at first, but often leads to increased complexity in maintenance, greater dependency on individual software specialists, and higher long-term total cost of ownership (TCO). Where decentralized self-built tools have grown out of control, simplify to be able to use off-the-shelf tools.

Partner with trusted experts and vendors (internal and external) to implement professional, well-established digital solutions.



Five situations with the potential to unlock productivity boosts

To ensure focus on measures that directly drive productivity, we suggest utilizing the following situations as impulses to check for possibilities for productivity improvements through simple digital tools.

Situation I: Manage personnel transitions

A line engineer is about to retire. They have introduced many improvements over the years, but with little documentation. The headcount is not re-approved.

Personnel transitions are a challenge to operational continuity. Especially in tough economic times, indirectly productive or “white-collar” headcounts may not be re-approved.

Digitalizing, streamlining and knowledge documentation is key to unlock productivity boosts, simplifying tasks for employees and making better-informed decisions.

This includes using so-called “self-service” low-code/no-code applications, in which teams can create and simplify workflows by themselves within defined limitations. Generative AI like chatbots also start to be very effective at optimizing knowledge work.



Situation II: Defer capital investments

Despite most lines running at low capacity, a special machine should be replaced as on time delivery is frequently endangered by this machine breaking down.

If critical machines and equipment are operating at full capacity and become a bottleneck, it seems necessary to make a large capital investment to meet targets.

Various digital tools can first be applied to defer or even avoid these investments. This includes optimizing downtime using digital maintenance systems and planning; controlling the material flow around the bottleneck asset by dynamic scheduling; and tweaking performance using digital simulations.

These digital tools would only add overcapacity if used incorrectly but can save millions applied in the right situation.



Situation III: Optimize energy consumption

Due to increasing energy bills, all production departments have been asked to come up with ways to save 10% of energy within 6 months.

With rising and volatile prices, energy costs have recently moved into the spotlight. Even simple actions like shutting down equipment when not in use instead of being on standby can lead to direct energy cost savings.

Dynamic planning of certain energy-heavy processes based on energy considerations can further improve savings.

Situation IV: Optimize resource allocation

HR limits the use of temporary workers and overtime as direct employee utilization is running low. But the flexibility of own employee shift planning is limited.

Underutilized shifts, hiring of temporary workforce or the payment of overtime cause high personnel costs.

Supervisors must often react spontaneously to staff fluctuations, especially during high sickness levels. A digitally maintained capability matrix for every worker assists suitable distribution of personnel on the shopfloor in dynamic situations.

A structured process applying digital lean methods can be used to continuously review and adapt the number of shifts and personnel required according to the upcoming production plan.



Situation V: Reduce tied up working capital

Due to high capital costs, a program to cut inventory levels is initiated. But production areas are already worried about not receiving material in time.

Tied up capital in the supply chain, frequently caused by high inventory levels, incurs costs especially if interest costs are high. When high inventory levels are flagged and improvements demanded, digital tools can support.

Frequently, reasons for late material deliveries or unusual deviations are not immediately evident, leading to manual error analysis, the search for lost material, and a tendency to add safety stocks.

Digital tools can help reduce tied up working capital by analyzing historical data to pinpoint areas where deviations occur most frequently or by using simple tracking tools at key problem points to facilitate material handling and planning.



The urgency of digital transformation: Why now is the time to act?

STRUGGLE FOR GROWTH AND SEARCH FOR OPTIMIZATION POTENTIAL

From investment to impact

Over the last decade, companies have poured resources into digitalization — building infrastructure, forming teams, and nurturing a digital mindset. Now, many are eager to shift gears from building the foundation to scaling the benefits of pilots without much further investment by leveraging synergies and learn best practices. The “low-hanging fruits” of digitalization have already been harvested by most and the foundational benefits have been known for a while.

However, opportunistic and demand-driven digital projects have led to isolated pilot applications, complex digital roadmaps and duplication of work in different areas of the same organization. Many initiatives lack an end-to-end view for a seamless integration into existing business processes and frequently rather focus on the introduction of “fancy technology” instead of efficient and user-friendly solutions that actually solve existing problems and contribute to operational KPIs.

Double-edged sword: The balancing act of targeted investments during uncertain times

The economic climate has cooled down in many relevant markets, demand has decreased, while excess production capacities still remain. Stricter regulations, especially around sustainability, add additional complexity. In these uncertain times, many companies are limiting investments to only the most targeted initiatives to help sustain the „business as usual“. Often only immediate, hard savings at the core business are evaluated, leaving even high-ROI supplementary or long-term projects postponed for a better time.

Nevertheless, especially right now it is essential not to “pause” the digital transformation. Defined topics with direct savings potential or strategic relevance should be continued using existing resources, competences and targeted investments. For this purpose, digitalization units require innovative approaches and pragmatic methods to convince their management.

WAYS TO REALIZE PRODUCTIVITY INCREASES DESPITE UNCERTAIN TIMES

Time to challenge the old ways

The current climate offers a unique opportunity to step back and reevaluate long-standing processes. Companies

often have more time than flexible budgets, making this the perfect moment to challenge deeply entrenched habits and simplify historically grown and complex processes. Often, the digital infrastructure is already there – now it is time to leverage it and identify potentials for improvement.

Many introduced systems are primarily used to steer processes and fulfill tasks instead of going one step further and deriving optimizations. For instance, value stream data gathered from an MES system should ideally be used to identify waste more quickly and precisely using digital lean methods, rather than relying on traditional lean approaches. This requires a defined process and a team of domain and operational excellence experts who make use of available data in continuous improvement projects.

Focus on what's already in your toolbox

Digitalization does not always involve buying new technology. Most companies already have tools, systems, and data in place, yet these resources are still underutilized. Now is an ideal time to focus on extracting more value from what already exists. For instance, leveraging internal capabilities by sending digital teams to regular operations meetings to listen to their colleagues' daily challenges can provide great collaboration value. Additionally, even simple initiatives, such as performing manual analytics, can lead to significant improvements at minimal cost.”

Embrace iteration over perfection

Instead of waiting for perfect conditions or flawless designs, adopt a mindset of iteration. Small, incremental changes can be implemented quickly, delivering value faster and building momentum for larger improvements over time. This approach reduces risk, maximizes agility, and ensures that every step contributes to tangible progress.

Rely on trusted partners for professional solutions

Do not always try to „reinvent the wheel“—in most cases, professional solutions are already available on the market. When a specific solution is needed, acquiring it from an external partner, rather than developing it in-house, will deliver quicker results, protect finances from unexpected and hidden lifecycle costs, and reduce reliance on individual software experts.

The future favors the adaptable

In times of uncertainty, flexibility is a superpower. Companies that adapt their processes, rethink their priorities, and embrace change will rise stronger. Digitalization is not just about technology; it's about creating a culture that thrives on innovation, agility, and continuous improvement – even in challenging times.

Quick impact toolkit: Practical steps for immediate results

“EXCEL-HUNTING” AND “ACCESS-HUNTING” TO STREAMLINE PROCESSES

Over time, many processes have grown, yet many of them remain unmapped in enterprise-level systems such as MES or ERP. This gap has led to complex and self-built Microsoft Excel sheets across various business and manufacturing processes. Similarly, Microsoft Access databases, which can be quickly created and managed by various users, are often deeply embedded in company processes. These self-built solutions have evolved historically due to their flexibility and extensive customization options for users. However, this reliance on ad hoc solutions often introduces significant challenges. The lack of transparency, limited process traceability, and the prevalence of redundant or inconsistent data undermine the principles of a „single source of truth“ and modern data governance standards.

Outdated processes design and lack of “single source of truth” can lead to media breaks during critical process steps to manually adjust, export and upload necessary documents. This leads to an increase in non-value-adding manual tasks, such as editing, copying, and pasting, which

can result in inconsistent or even inaccurate data management. Changes are typically known only to the data owner, creating significant business risks in cases of absence or employee turnover.

„Challenging the old ways“ should include conducting a structured review of Microsoft Excel sheets and Microsoft Access databases that are either integral to core processes or part of unintended shadow processes. Shadow processes often deviate from defined workflows, exacerbating issues with inconsistent and untraceable data. Efforts to identify and address reliance on such self-built solutions should focus on uncovering poorly designed aspects of underlying processes, emphasizing the root causes that prompted the development of such solutions.

In the initial phase, a structured search is essential to identify tools and media breaks within processes and to critically evaluate the validity of certain information. Over time, self-built spreadsheets and databases should be gradually phased out and replaced with professional application systems and databases that align with governance standards for process execution and data storage.

Hidden inefficiencies after MES implementation: Operator workarounds, workflow gaps, and shadow processes

A manufacturing company conducted a stepwise analysis of key workflows within its value stream and identified that several processes associated with its newly introduced MES system were being operated as shadow processes using Microsoft Excel and even printed lists. Further investigation revealed that operators relied on Excel and paper to document tasks, even though the MES system provided similar functionality.

The analysis uncovered that despite having terminals, these were not optimally positioned, forcing operators to walk and sometimes queue. Barcode scanners existed, but were not ergonomically placed, leading many operators to ignore them. Where paper lists were still used, the old process of stamping or signing by operators when completing steps was still in place despite already being possible in the MES with a digital signature by tapping an access card.

After initially adding more terminals and relocating the barcode scanners to more convenient locations, operators and team leaders have not received proper training. This lack of training led to some factory areas still relying on a shadow Excel or paper despite already eliminating the reason for it.



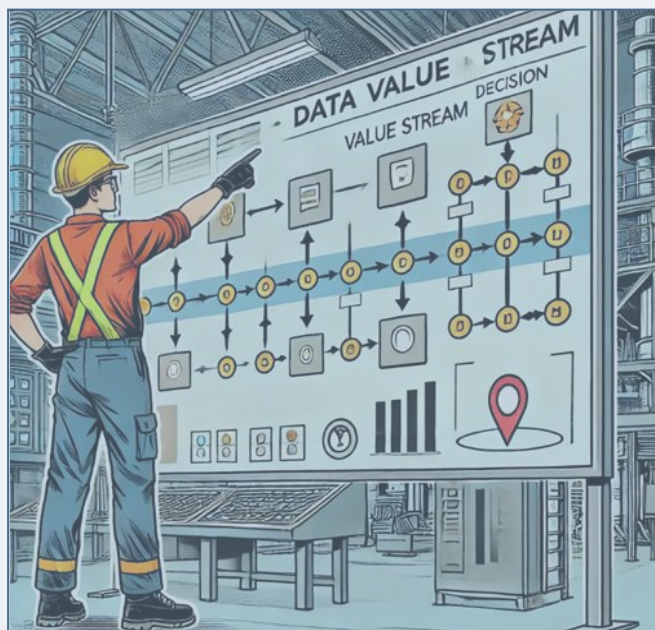
CONDUCT DATA VALUE STREAM MAPPING FOR CRITICAL PROCESSES

Data value stream mapping can be used to map critical processes and identify weaknesses such as media breaks (e.g. reliance on self-built sheets), missing data, or redundant data storage. After mapping, suitable measures for improvement can be derived for any digital project, process or use-case. One of the key strengths of this approach is its ability to be executed in sprints, enabling the targeted implementation of digital use cases within defined time frames (e.g., 4-8 weeks), rather than resulting in yet another '80% done' project.

To ensure success, assemble an interdisciplinary team of experts from IT, lean management, digitalization, and the specific process domain. This team should have access to all relevant internal specialists and data owners to combine the necessary knowledge and drive the initiative effectively.

The data value stream mapping process typically involves the following steps:

- 1. Define the relevant information** for the target use case (e.g., specific KPIs).
- 2. Map the current state step by step.** How does data flow today and from which data sources? Where are media breaks? Using a flexible visualization tool, such as Microsoft Visio, is highly recommended.
- 3. Define criteria to characterize data requirements.** Frequency of collection, immediate or delayed transfer, level of aggregation, adding of timestamps, etc.
- 4. Define a target state.** How can media breaks be eliminated? From which systems will data flow in the future? What are relevant data characteristics?
- 5. Define concrete measures.** Assign responsibilities and set defined timeframes to move towards the target state as quickly as possible.



Streamlining KPI management: Automating data integration for Gemba meetings with data value stream mapping

A manufacturing company required heterogeneous data from multiple sources for its daily Gemba meetings of critical metrics such as production output, product quality, or on-time delivery rates. Over time, these measures have deviated from the automatically calculated measures provided by the relevant MES system. In many cases, manual preparation of these data points was required on a daily basis in complex sheets to present corresponding KPIs and historical trends on dashboards, leading to incomplete and error-prone output.

Data value stream mapping conducted across multiple plants with similar production processes allowed for identification of a core set of indicators which could automatically be calculated, clearly mapped and stored, and even compared between value streams.

DERIVE IMPROVEMENTS WITH DIGITAL LEAN AND BASIC STATISTICAL ANALYSIS TOOLS

When discussing data analysis in the context of Industry 4.0, many envision advanced, complex models requiring a dedicated team of data analysts. In reality, however, data of sufficient quality and quantity is often lacking, and advanced analyses are typically limited to isolated points, such as the process parameters of a modern CNC machine, rather than covering end-to-end processes.

In the current environment, companies can leverage their existing data and infrastructure to manually derive improvements without requiring significant investments or large teams of data analysts. The potential of simple statistical analyses and digital lean tools is often overlooked, yet they can deliver substantial benefits to identify recurring patterns and incoherent processes.

Basic statistical methods from Six Sigma, such as histograms, outlier detection, regression or correlation analysis, are particularly effective when applied to value stream data (e.g., cycle times, changeover times). These tools can first be applied manually in an explorative way to find issues quickly, and later stabilized to alert for known situations.

Uncovering hidden patterns: How data visualization improved changeover efficiency

A manufacturing company was facing an unusually high variance for changeover times at one machine, which frequently disturbed production planning. By plotting the changeover times in a histogram, the team identified that they actually had two distinct changeover processes based on the distribution. The solution was to split the processes in production planning and allocate a different number of operators to each, reducing the machine's average changeover time by approximately 30%.

Digital lean builds on classic lean management principles, such as line balancing, value stream mapping and root cause analysis, while leveraging live, continuous value stream data to faster detect and analyze occurring waste in processes. In this context, a value-adding approach can be to establish a dedicated "Digital Lean Team" that combines classic lean manufacturing tools with analysis of available data to drive improvements.

Such interdisciplinary teams are well-suited to integrate related methods, such as systematic searching for self-built sheets and databases in processes or data value stream mapping, into their workflows. Additionally, they can incorporate findings into upskilling programs for internal staff, ensuring the organization builds sustainable capabilities for continuous improvement.

When lean meets digital: Collaboration for continuous improvement

A manufacturing company established a tactical team of lean and digitalization experts, who systematically analyze data from the existing infrastructure, such as value stream data from their MES, to identify waste in the current process and derive improvement projects. The team uses basic statistical methods, and flexible tools like Microsoft Excel or Minitab to perform "by hand" analyses of existing data.

When the lean team identified an issue, the digital team would visualize available data, contrast between possible contributing factors and iteratively with the lean team narrow down the reason. After fixing the issue, an automatic rule would be deployed to their production data system to alert in case of the situation occurring again.



Where digitalization pays off: Key situations for productivity and cost savings

The whitepaper highlights **five situations** where productivity can be increased through process optimization, elimination of unnecessary activities, better utilization of existing data and infrastructure, and highly targeted investments.

1. **Managing personnel transitions to ensure operational continuity** focuses on tools to maintain seamless operations during workforce changes while enhancing productivity and eliminating non-value-added activities.
2. **Defer capital investments by increasing productivity of bottleneck assets** explores methods to maximize the utilization and performance of bottleneck assets, delaying the need for significant capital investments.
3. **Optimizing energy consumption in energy-intensive processes** emphasizes solutions to reduce unnecessary running time of energy-intensive equipment by aligning production needs with energy costs.
4. **Optimizing fine-planning to eliminate underutilized shifts** highlights approaches to improve workforce allocation and balance production shifts for better resource utilization.
5. **Reducing working capital tied up across the value stream** provides insights into streamlining material flows to shorten lead times and free up financial resources.

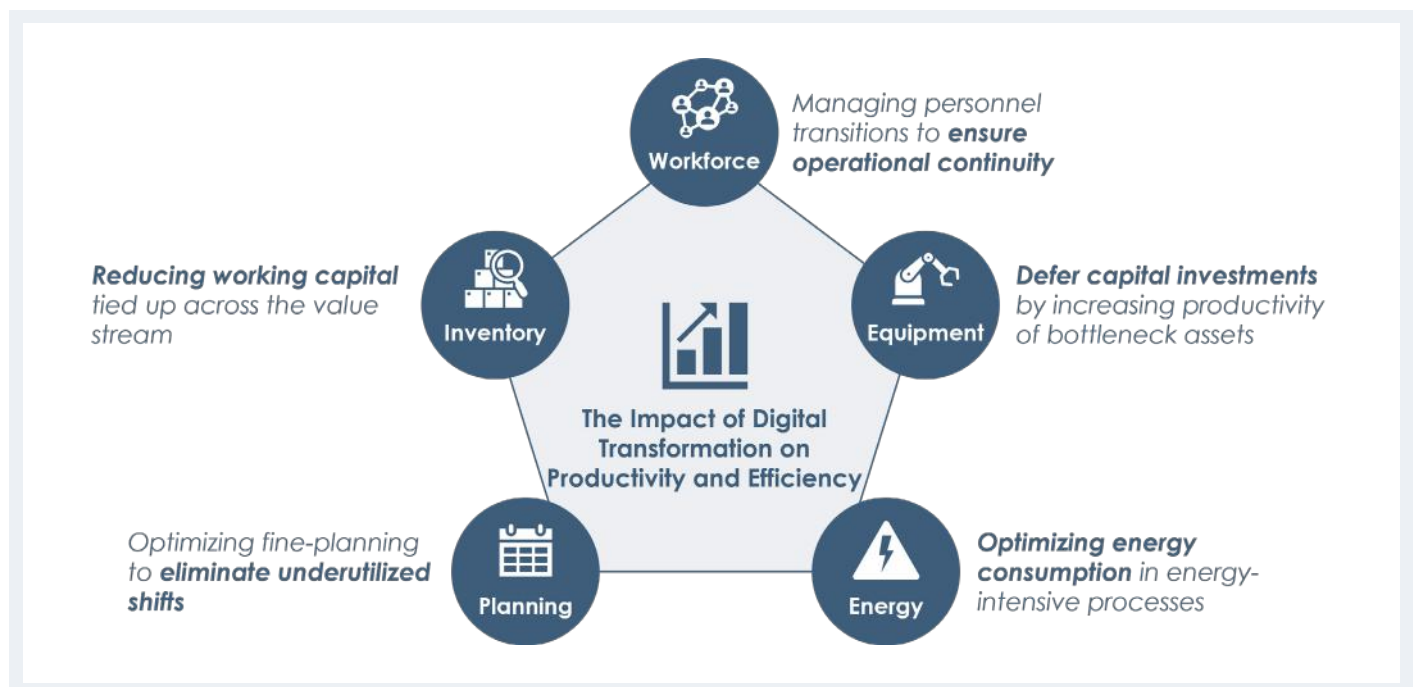


Figure 1 Digital transformation productivity levers

4.1 Managing personnel transitions to ensure operational continuity

Personnel transitions are inevitable in any organization and present a significant challenge to operational continuity. To maintain seamless operations during such changes, proactive strategies that address employees' efficiency and adaptability may be implemented.

At the same time, such transitions are also a good time to question established practices and leverage optimization potential.



OPTIMIZING WHITE-COLLAR WORKFORCE EFFICIENCY

Implement self-service low-code/no-code applications to reduce unnecessary manual work and optimize workflows

Administrative employees often spend significant time on repetitive tasks, such as data entry into ERP systems, fulfilling order requests, or navigating unnecessary process steps within their scope of work. The situation worsens when a team member retires and the headcount is not reapproved, forcing inexperienced employees to take on the tasks, which further increases the time spent on them. For instance, a warehouse supervisor responsible for managing paint inventory at an automobile factory may spend much of their day on procurement documents and ERP updates. Time that could be better spent optimizing material flow, inventory allocation or reducing lead times between inventory and production.

Routine tasks hinder white-collar workers' productivity, yet their automation is rarely prioritized by the IT department.

Traditional development methods for internal tools often demand significant IT resources and investments while rarely resulting in immediate cost savings due to higher life-cycle costs of self-built solutions. As a result, internal tools, such as an automated approval workflow in a procurement process, often have low priority within the IT roadmap, which means that employees keep spending time on necessary, but time-consuming tasks, instead of focusing on those that require creativity or expert knowledge.

Self-service low-code/no-code platforms empower employees to automate monotonous tasks, conserve IT resources, and enable bottom-up process optimization and adaptability.

Key steps for implementation:

- 1. Eliminate unnecessary activities.** Identify and eliminate redundant activities (e.g., requesting data from another department by e-mail or phone instead of using a central system) through process optimization within or across departments. Redundant activities should be eliminated entirely whenever possible, rather than being automated.
- 2. Differentiate routine and expert activities.** Some activities are repetitive yet crucial for the production process (e.g. purchase orders classification and entering data into ERP system). Prioritize these activities and automate accordingly, for instance, based on the time savings. These activities should be prioritized based on their benefits (e.g., time savings) and automated accordingly. In contrast, expert activities that demand specific domain knowledge, expertise and creativity typically fall outside the scope of automation.
- 3. Leverage established solutions.** Use trusted platforms that might already be available in your company, such as Microsoft PowerAutomate, to avoid introducing additional systems that increase IT complexity.
- 4. Enable collaboration and knowledge sharing.** Regular training sessions and meetings encourage employees to share knowledge and best practices, accelerating the creation of templates using standardized toolkits. The ongoing training process may involve a broad range of stakeholders expanding the internal toolkit.

REDUCING UNNECESSARY EFFORTS FOR GETTING WORK INSTRUCTIONS

Implement mobile work instructions and task documentation to minimize time spent by staff on unnecessary walking or information gathering

One of the often-overlooked inefficiencies in manufacturing environments is the unnecessary time and movement of staff to access work instructions, find information or document fulfilled tasks. The cumulative time spent on the phone or walking back and forth can result in lost productivity.

Inefficient information access leads to wasted time and unnecessary motion but often going unnoticed.

For instance, a machine operator is about to start a production order but notices the most recent version of the technical drawings is missing. To resolve this, the operator must leave their workstation, consult the line manager, and even escalate the issue to the R&D department. This often involves waiting for a digital response or physically walking to another building to retrieve the file.

In maintenance, similar inefficiencies arise. When technicians respond to a machine failure, they visit the site to assess the issue but often must return to a central office to retrieve manuals, log the problem, or check historical maintenance records. These repetitive movements are not only time-consuming but also disrupt workflows, delaying resolution.

Mobile-enabled workflows allow real-time task allocation, information updates and documentation, and collaboration, reducing non-value-added activities.

By equipping staff with mobile devices that provide real-time access to instructions and documentation and making sure information is available, such unnecessary movements can be eliminated. Operators and technicians can access real-time instructions, documentation, and historical data directly from their location. Maintenance staff can log machine failures and retrieve repair manuals on-site without needing to return to their desks.

Mobile solutions can also enable dynamic task allocation for logistic tasks. Instead of looking for materials that need to be moved, logistic operators can receive real-time updates when finished goods or subassemblies are ready to be transported. This ensures timely and efficient material handling, reducing idle time for machines and operators.

The cumulative productivity gains from reducing the lean waste of excessive motion can lead to significant cost savings.

Mobile solutions can be efficiently developed in-house using low-code platforms, providing flexibility and cost control. The key is ensuring seamless integration with existing systems to leverage current infrastructure effectively. Depending on the process, this might interface ERP, MES or other relevant systems. Aligning the user interface design closely with workflows and involving operators and technicians during the development phase will ensure the solution meets their needs. Platforms like Microsoft PowerApps or SAP Fiori provide the flexibility to quickly build such task-dependent interfaces while directly interfacing the real leading system rather than introducing more spreadsheets or intermediate solutions.

Key steps for implementation:

- 1. Map required information.** Identify the locations of critical information (e.g., technical guides, instructions) relevant to maintenance, logistics, and production tasks. Prioritize tasks based on the longest travel routes, the most unconventional information sources (e.g., paper-based), and their criticality.
- 2. Assess effort to provide information at the place of work.** Estimate the costs associated with converting documentation into digital formats (if required) and calculate the potential savings in man-hours.
- 3. Eliminate the need to collect information, where possible.** Transfer workflows to mobile-friendly formats to minimize unnecessary movement.
- 4. Cluster information to avoid multiple tours where elimination is not possible.** Where it is not avoidable to manually collect information, explore preparing it in such a way that it only needs to be fetched once instead of frequently.

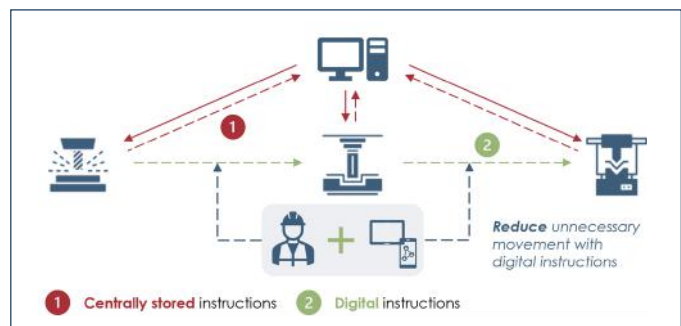


Figure 2: Optimization of worker's movement with digital instructions

4.2 Defer capital investments by increasing productivity of bottleneck assets

When production output needs to be increased or stabilized, there is often a call to invest in replacing or duplicating bottleneck assets. However, opportunities to enhance the productivity of existing bottleneck assets often go unnoticed, despite the potential to unlock significant productivity gains without costly investments. Exploring these opportunities should be a priority before making any capital investment decisions.

Digital tools can help identify and prevent productivity losses in existing assets. Although these tools may frequently require initial investments, delaying large capital expenditures can often offset these costs.

Immediate capital expenditures can often be avoided by leveraging data to better utilize assets in changing situations. This can help enhance availability, either by reducing downtimes caused by maintenance or material flow issues, or by optimizing parameters to improve asset performance. Although of course quality is a third crucial aspect of equipment effectiveness, we exclude it here as data-driven quality problem elimination is already well-established and commonly integrated into operational processes.



PREVENTING DOWNTIME OF BOTTLENECK MACHINES

Dynamically allocate maintenance resources based on the target impact-driven KPIs to increase availability of bottleneck machines

Stable production output relies heavily on the availability of bottleneck assets. However, these assets are often neglected in terms of proactive maintenance and inspections due to their constant overutilization. Frequently pilots for digital maintenance solutions have also not been done at bottleneck assets as paradoxically these were deemed too critical to actually implement new tools.

Also, often these assets are older or more customized and require more retrofitting to get relevant data. As a result, maintenance teams are frequently occupied with less critical tasks, leaving production vulnerable to significant risks.

If significant downtimes of bottleneck assets occur, a proactive and dynamic maintenance strategy based on KPIs such as machine availability, runtime, and failure rates should be adopted.

Maintenance of bottleneck assets can be proactive and KPI-driven, not based on urgent phone calls or fixed schedules. By prioritizing maintenance tasks based on the machine's actual condition and its impact on production, the maintenance team can ensure that the most critical issues are addressed first. A dynamic maintenance strategy focused on the availability of bottleneck assets can stabilize the production output under changing circumstances without the need for capacity expansion.

Integrating maintenance scheduling with production planning further optimizes maintenance activities and increases the availability of critical assets.

Instead of maintaining separate schedules, maintenance tasks can be carefully planned and coordinated alongside production shifts. This requires close communication between the production and maintenance teams and an integrated planning view in a proper system as opposed to a set of spreadsheets, ensuring that preventive maintenance is carried out during periods when equipment is not being actively used for production, such as shift changeovers and breaks.

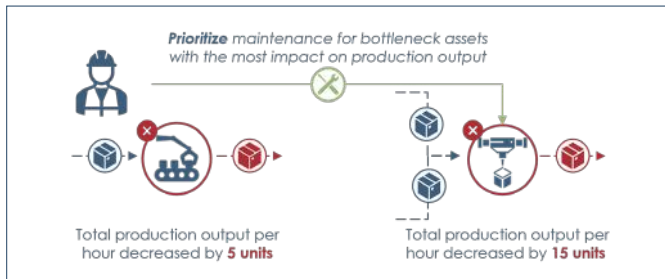


Figure 3: Impact-driven maintenance of bottleneck assets

Key steps for implementation:

1. Establish key KPIs. Define KPIs for bottleneck assets and align them with production demand. Collaborate with relevant departments (e.g., maintenance, production) to identify key metrics for availability (e.g., downtime) and performance (e.g., failure rate).

2. Prioritize maintenance tasks based on established KPIs. Work with the maintenance team to establish a proactive maintenance process for bottleneck assets based on the identified KPIs. Include bottleneck asset availability as an additional KPI for maintenance teams.

3. Integrate proactive maintenance with production plans. Align maintenance and inspection tasks with the production schedule, considering planned machine downtime (e.g., shift changeovers). Coordinate with the production team to avoid disruptions in the workflow.

4. Introduce simple condition-based monitoring. Implement sensors or use data retrofitting techniques to equip maintenance team with relevant machine data, optimizing their maintenance schedules and preventing unexpected critical breakdowns based on real-time data.

MINIMIZING IDLE TIMES OF BOTTLENECK ASSETS

Maximize the availability of bottleneck assets through digital planning and optimized upstream buffer levels

The availability of bottleneck assets is often limited by tasks that could be delegated to less critical machines, ultimately reducing production output. For instance, an advanced multi-axis milling machine is often assigned to mill simpler geometries or cavities, which reduces its availability for special jobs that only it is capable of performing.

Even with well-planned material flow and proper buffer allocation, production output may still fluctuate, particularly when dealing with multiple variants that have different cycle times. This often results in a trade-off between opening new work centers and maintaining existing ones, a process typically managed manually by experienced staff.

Limited availability of bottleneck assets during fluctuating production demands often leads to a desire to add expensive machines or overstock buffers to meet capacity needs for specific jobs.

Digital planning systems can dynamically allocate tasks to the most suitable resources, ensuring bottleneck assets are utilized efficiently and during peak times reserved for tasks that require their unique capabilities.

Accurate live data on machine status, cycle times, and daily production and maintenance schedules can be integrated into the digital planning system to iterate an optimized schedule and efficiently reroute tasks from bottleneck assets, increasing their availability for the process critical tasks.

Minimizing buffer allocation through statistical analysis of historical production data ensures consistent throughput without waste and overstocking.

Key steps for implementation:

1. Identify sources of non-critical tasks. Determine which tasks are reducing the availability of bottleneck assets. Analyze the main sources of these tasks and identify the reasons they are assigned to these machines (e.g., underutilization of less critical assets, overproduction, or lack of safety buffers for bottleneck assets).

2. Identify tasks that could be reassigned to less critical machines. Collect data about availability of the machines and production schedules to dynamically reallocate tasks to underutilized resources or create safety buffers.

3. Integrate digital planning. Leverage value stream data within digital planning systems to take advantage of automated schedule optimization suggestions and process adjustments.

4. Determine the minimum possible safety level using statistical analysis. Analyze historical data alongside production plans, applying basic statistical methods (e.g., mean and standard deviation) to calculate the minimum buffer level necessary to prevent workflow disruptions.

OPTIMIZATION OF BOTTLENECK ASSET PARAMETERS TO INCREASE PERFORMANCE

Manually optimize (process) parameters of bottleneck assets in a continuous "try, measure and learn" feedback cycle to increase asset performance

Before considering investments in new equipment to increase production capacity, the performance of existing bottleneck assets should be fully optimized. However, once a production process is stabilized, its parameters often remain static, prioritizing consistency over optimization and leaving the asset's full potential unrealized.

Rigid process parameters can hinder the optimization of cycle times and production throughput, leaving significant potential untapped.

For instance, in an injection molding operation, parameters like back pressure and injection speed were fixed to ensure stable quality. Over time, this approach prevented adjustments that could have improved throughput without compromising product quality, especially during volatile situations, such as demand peaks.

A "try, measure, learn" approach facilitates transformation of manual, data-driven improvements – typically carried out by process experts and machine operators – into a stable and continuous improvement cycle to improve bottleneck performance.

Cross-functional team members with expertise in digital, lean, and domain areas can be assembled to explore parameters impact on a relevant KPI within the safety production range. For instance, adjustments can be made to injection pressure to observe their impact on relevant production KPIs. If the required product quality is maintained, the newly identified process parameters can be implemented.

Although scrap products may be produced during the 'try' phase (e.g., insufficient quality), the potential positive effects from adjusted parameters, when scaled from the test batch to full-time operation, will offset the testing costs and enhance asset performance.

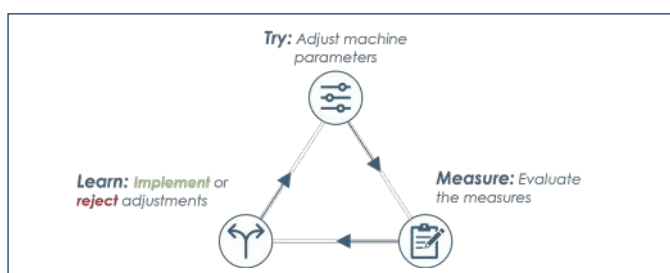


Figure 4: „Try, learn, repeat“ process

Key steps for implementation:

- 1. Collect process and machine data.** Create a central data storage system to store data collected either manually or through technologies like sensor tapping.
- 2. Apply statistical methods to measure the impact of process adjustments.** Use Statistical Process Control (SPC) to analyze historical data and during live process parameters monitoring. Test adjustments iteratively while observing their impact on relevant KPIs.
- 3. Involve process experts to steer feedback and control loops.** Successful adjustments should be implemented into standard operating procedures, while unsuccessful ones can be logged for further analysis. This adaptive and iterative approach ensures process improvements are both data-driven and flexible.

SIMULATION OF BOTTLENECK ASSETS TO INCREASE PERFORMANCE

Implement a digital twin of bottleneck assets for parameter simulation to increase the output per time

Although the data-driven 'try, measure, and learn' approach can yield performance improvements, these are often iterative and incremental. When a significant increase in production capacity is required and resources are available, a more advanced solution, such as a digital twin, may be better suited to rapidly achieve optimization potential.

Developing digital twins can be worthwhile despite high resource requirements, since they can result in greater optimization leaps in less time, compared to small and manual improvement iterations.

However, the data needed for machine learning (ML) model training is often unavailable in production environments, as it requires the collection of intentionally flawed data to identify the acceptable range of parameter settings for future simulations. Even when sufficient data is available, purely data-driven simulation models may have a risk of generating wrong and dangerous parameter settings outside the acceptable operational range, due to the lack consideration for physical constraints.

A digital twin that combines data-driven and physical modeling enables safe parameter exploration and optimization without jeopardizing system performance or personnel safety.

Combining data-driven approaches with physics-based modeling creates a hybrid framework for optimization called Physics-informed Machine Learning (PIML). This approach integrates empirical data with physical constraints to produce more accurate, realistic, scalable, and safe models. These models support robust simulations, guiding adjustments that enhance performance while remaining within operational limits. For instance, simulations can explore increasing spindle speeds in CNC machines or optimizing belt speeds in special machinery. Once validated in the virtual environment, these parameters can be safely implemented in real-world production.

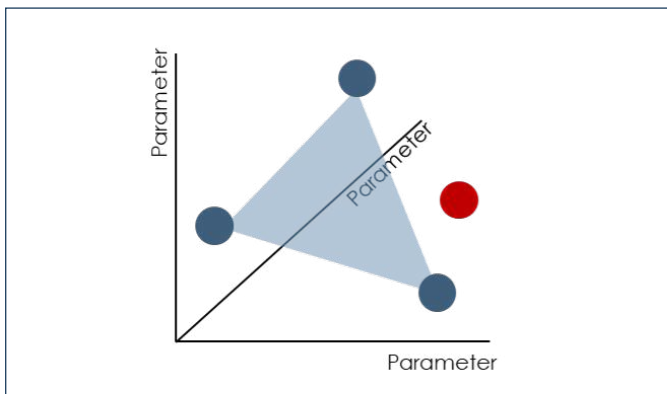


Figure 5 Exploration of equipment parameters beyond the known range

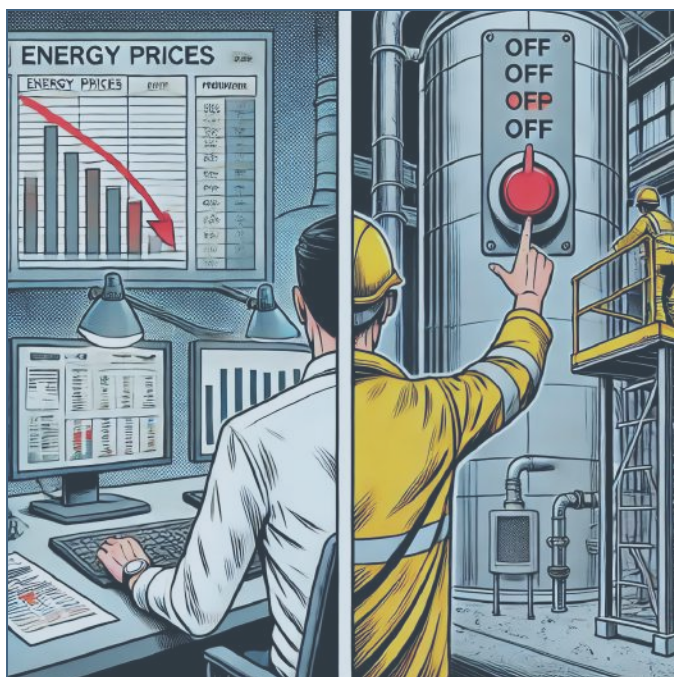
Key steps for implementation:

- 1. Evaluate the potential effect.** Prioritize assets for implementation based on calculated optimization potential, process criticality, and the availability of relevant data.
- 2. Clearly define use and business case.** Establish an initial hypothesis, target state, and relevant KPIs to track project progress and enable iterative adaptations based on observed results.
- 3. Identify data and process gaps.** Address data gaps through solutions, such as sensor retrofitting, I to ensure comprehensive data integration.

4.3 Optimizing energy consumption in energy-intensive processes

Optimizing energy consumption in energy-intensive processes is a major cost-saving opportunity. By proactively managing and adopting energy usage, organizations can significantly reduce operational expenses without compromising productivity. Effective energy optimization can be done by aligning production processes with energy demand and cost fluctuations.

By reducing unnecessary energy use during idle periods and prioritizing energy-intensive tasks at optimal times, companies can maintain production efficiency while reducing unnecessary costs.



MINIMIZING EQUIPMENT STANDBY DURING IDLE PERIODS

Align equipment working hours with the production plan and prioritize switching it off during idle times to reduce energy consumption.

In manufacturing facilities, equipment often continues running or remains in idle mode during periods of inactivity, such as shift changes, lunch breaks, or unscheduled delays, leading to ongoing energy consumption. While this standard practice aims to simplify operations for machine operators, it frequently goes unnoticed and contributes to higher operational costs.

Optimizing energy consumption of the idle equipment is an effective and easy way for reducing energy costs.

In certain scenarios, leaving equipment switched on or in standby mode is justifiable. For instance, if it affects critical set up times or keeping a stable temperature level. Shutting down such equipment during short breaks could result in greater energy losses or time efforts due to the need to reheat or recalibrate.

However, switching off equipment such as CNC machines or quality control systems like Coordinate Measuring Machine (CMM) during idle periods could be feasible. When a CNC machine is waiting for considerable time for the next batch of components or a CMM is used to just test specific high-profile jobs a few times in a shift, there is a significant opportunity to save energy.

Shutting down certain equipment during longer breaks or extended idle times reduces unnecessary energy consumption without compromising production.

With dynamic capacity steering based on live data, periods of inactivity can be identified and managed more effectively. For instance, when delays are detected in upstream processes, equipment can be shut down to reduce unnecessary energy consumption without impacting overall production timelines.

It is important to establish clear guidelines indicating which equipment can be powered down and under what circumstances to maintain optimal production efficiency.

Furthermore, education and experience of machine operators are also important for understanding the importance of aligning equipment usage with production schedules to reduce energy costs and in identifying the appropriate timeframes for adjustments.

Key steps for implementation:

- 1. Prioritize machines with the highest energy consumption during idle times.** Analyze historical data to identify machines that spend the most time in idle mode and assess their energy consumption during these periods.
- 2. Identify optimal timeframes for shutting down machines.** Perform statistical analysis to align idle periods with times of high energy prices and the production schedule, determining the most suitable timeframes for completely shutting down the machines.

PRIORITIZATION OF ENERGY-INTENSIVE PROCESSES DURING OFF-PEAK HOURS

Consider dynamic energy prices in production planning to move energy-intensive processes to off-peak hours and reduce energy costs.

Rising electricity costs have been a critical topic in the past years and the economic benefits arising from energy efficiency have not been fully exploited. Energy management capabilities are mostly limited to monitoring, analysis, and reporting. Energy-aware manufacturing where operational decisions take energy efficiency more into consideration is not yet a standard practice. For instance, German companies have access to dynamic electricity prices, resulting in incentives to make load shifting of manufacturing operations more flexible.

The flexibilization of load shifting in energy-intensive production processes can lead to considerable energy savings with dynamic electricity prices.

For instance, dynamic electricity prices can be useful for energy-intensive processes such as heat treatment, which cannot be switched off in the middle of a shift. However, if flexibility mechanisms such as suitable buffers exist, production scheduling can align with electricity prices as good as possible to run energy-intensive processes during off-peak hours.

Energy supply-optimized production planning reduces electricity costs based on required electricity, known load profiles and dynamic electricity prices.

Production plans are predominantly driven by customer demands and availability of internal manufacturing re-

sources. Adding the factor of dynamic electricity prices requires capabilities to calculate peak load requirements in the factory based on current production plans and known load profiles of manufacturing processes as well as the integration of dynamic electricity prices (and weather conditions if own electricity producers such as photovoltaic are available) for energy supply-optimized production planning. The results are provided to production planning with suggestions for load shifting for optimal operating schedules depending on price forecasts for the energy sources involved.

With this approach, larger electricity consumers such as laser cutting, painting or the production of media can be given priority when cheap solar power is available. With greater flexibility and a suitable value stream design, even shift schedules can be aligned with weather forecasts and cheap electricity.

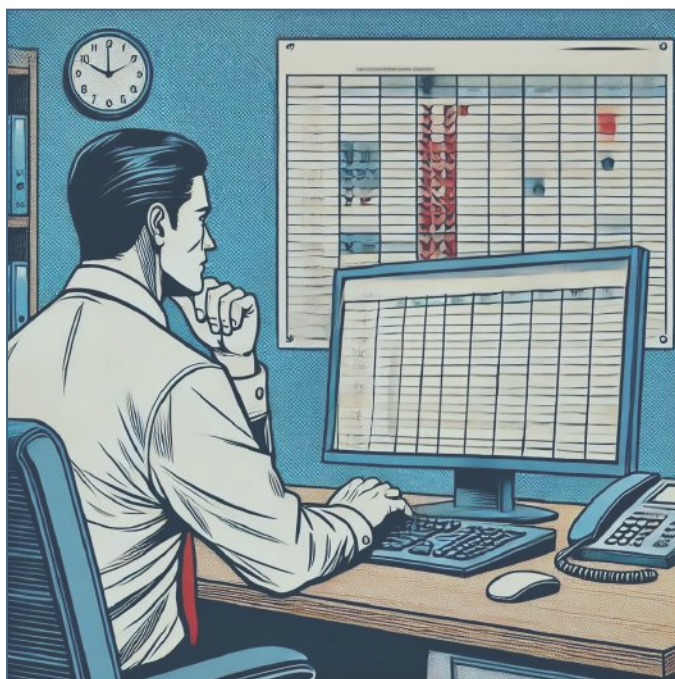
Key steps for implementation:

- 1. Identify energy-intensive processes using historical data.** Use historical energy consumption and machine data to identify which share of energy-intensive processes occurred during peak hours.
- 2. Align the production plans with electricity prices.** Integrate electricity prices as another factor in production planning, alongside customer demands and internal capacities.
- 3. Prioritize energy-intensive processes to off-peak hours, if possible.** Explore opportunities of rescheduling certain energy-intensive activities during off-peak hours without affecting production output.

4.4 Optimizing fine planning to eliminate underutilized shifts

Underutilized shifts represent an inefficiency that can inflate costs and strain resources without delivering proportional value. These shifts may still be in place due to the fear of not meeting production targets if they are to be eliminated. Eliminating these shifts, however, can lead to significant cost savings both in terms of workers and utilities. Desired production output could be achieved through a refined approach to fine planning that ensures every shift operates at its optimal capacity while maintaining workforce balance and flexibility and preserving the desired production output.

By using statistical tools to analyze shift performance, and ultimately by adopting dynamic planning, organizations can effectively address production imbalances. This enables more efficient use of resources, reduces reliance on costly overtime or temporary labor, and ensures consistent output across shifts.



OPTIMIZATION OF SHOPFLOOR PERSONNEL PLANNING

Dynamically plan for staff shortages based on a capability matrix to allocate tasks, reducing the need for overtime and temporary workers.

Personnel costs have a major share in overall manufacturing costs and optimizing staffing without compromising

production can lead to significant savings. A common challenge is managing staff shortages due to sick workers or other unexpected absences.

Instead of relying on temporary staff or paying for overtime, companies can utilize dynamic planning based on a capability matrix to optimize the use of their existing workforce during staff shortages.

By implementing a capability matrix, companies can identify which workers can perform specific tasks across different machines and production processes. With dynamic personnel planning, tasks can be allocated based on this capability matrix. This allows for better utilization of existing staff without the need to hire extra workers or pay for workers' overtime.

For instance, if a skilled operator is suddenly unavailable, reassigning tasks between workers based on verified skill sets helps maintain productivity without the need for additional hires or overtime.

Process analysis is necessary to identify skill gaps that can be filled by targeted training of specific staff.

By analyzing process bottlenecks and using a capability matrix, the skills that need development can be identified and added to the training schedule. For instance, if the number of employees with welding, high voltage handling or forklift driving certifications are critical to ensure a shift runs at full capacity, planning to upskill some workers may make sense if in turn this leads to avoiding overtime or extra shifts due to lost capacity in cases of sick leave.

Key steps for implementation:

- 1. Collect and prioritize capabilities.** Gather capability requirements from supervisors and machine operators, prioritizing those necessary for the most critical machines.
- 2. Introduce a simple storage source.** A basic digital tool can suffice, as long as supervisors and line managers can quickly navigate it to reallocate tasks and identify skill gaps.
- 3. Prioritize development of limited capabilities.** Identify the most frequently absent but essential capabilities needed across different machines. Involve experienced personnel in training and focus on establishing a base level of skills to ensure smooth operations.



Figure 6: Staff optimization

BALANCING PRODUCTION SHIFTS

Leverage digital lean tools to dynamically balance production shifts, ensuring optimal utilization with minimum number of shifts

When no established process exists to dynamically align the number of shifts with the production plan, resources may remain idle during low-demand periods, while sudden demand spikes may require unplanned additional production hours or even shifts to meet production targets. This results in increased costs from underutilized workers and machines.

Dynamically balancing production shifts using historical data and production plans ensures an optimal number of shifts with maximum utilization of workers and machines, maintaining a buffer for sudden demand peaks.

By analyzing historical data, suboptimal scheduling patterns, such as consistent underutilization of evening shifts, can be identified. Simple scheduling software can then be employed to reallocate tasks and iteratively redistribute capacity based on production plans, ensuring stable production output.

For instance, this approach could involve reassigning tasks between morning and evening hours or reallocating workers from weekend shifts across the week, reducing idle time and overtime costs while maintaining sufficient production coverage.

Key steps for implementation:

1. Analyze historical production data. Identify patterns in demand and capacity using statistical analysis, focusing on underutilized shifts. It may include, for instance, calculating takt time to determine the production rate needed to meet customer demand and identify the necessary number of workers to operate machines efficiently.

2. Redistribute tasks and resources. Reassign tasks across shifts to minimize idle time, avoid overburdening workers, and eliminate costly overtime, ensuring that the machine use aligns with shift changes. Prioritize redistributing resources from the most underutilized and expensive shifts, such as weekend shifts, to standard workdays.

3. Monitor and adjust schedules. Regularly review and update shift schedules using real-time production data with short- and mid-term plans, ensuring stability of the production output in times of expected demand shifts.

4.5 Reducing working capital tied up across the value stream

Excess working capital tied up in the value stream is costly. One of the key drivers of this inefficiency is the prolonged inventory holding time, caused by process bottlenecks and deviations.

By focusing on reducing process inefficiencies and leveraging data-driven insights, organizations can identify and address the root causes of delays. Streamlining these processes not only accelerates material flow but also minimizes the capital locked in the system.



REDUCING PROCESS INEFFICIENCIES TO SHORTEN MATERIAL LEAD TIME

Conduct data-driven investigation to identify areas most prone to errors and delivery time deviations.

At a manufacturing company, persistent supply chain delays and errors disrupted production schedules and forced employees into non-value-added activities, such as searching the factory for lost material deliveries. Misallocated or missing materials caused shortages in critical areas and overstocking in others, creating additional challenges for production planning and resource allocation. These inefficiencies also tied up capital in „lost parcels“ and excessive inventory, left idle and unused somewhere within a factory.

Manual decisions, spreadsheet-based tracking, lack of navigation tools for suppliers and the absence of a centralized 'single source of truth' for supply chain planning and status updates have led to error proneness.

Conducting data-driven investigations helps pinpoint specific areas with frequent delivery time deviations.

Key steps for implementation:

- 1. Explore historical data to identify recurring bottlenecks using statistical analysis.** Historical information about lead times, delivery routes and warehouse operations can be used to identify patterns. Use statistical methods, such as calculating standard deviations of processing times along handover points.
- 2. Measure and learn from the implemented initiatives.** Focus on the results of implemented initiatives to drive the continuous improvement process, based on identified patterns and tested solutions. Roll out insights across similar processes and share successful practices between departments to more quickly identify root causes and effective solutions.

AUTOMATE TRACKING

Introduce basic tracking and tracing tools to minimize human errors during material planning and allocation.

In addition to identifying the most problematic areas through data-driven investigation, tracking material through digital means provides an extra layer of data to measure the effectiveness of implemented solutions and establish a feedback loop for continuous improvement. Ultimately this can be extended to tracing information to allow seamless tracking and tracing across the value chain, but for value stream optimization, often just tracking the flow of goods is a good starting point to feed manual data analytics and improvement projects and is less costly to implement.

Introducing simple digital tracking mechanisms, such as QR-codes, at key trouble points in the supply chain enables material traceability, improves allocation accuracy, reduces lead times and supports decision-making during disruptions.

Key steps for implementation:

1. Identify and prioritize the right processes and level of detail. Some processes, such as painting and heating, are not naturally trackable due to changes in the initial form. Additionally, precise tracking (e.g., tracking each individual part) is often not feasible and requires significant effort to implement. Therefore, make sure to prioritize processes that provide the most benefits with minimal investment and complexity.

2. Deploy simple tracking tools. For instance, basic QR codes for internal material tracking (e.g. on boxes), time stamps or digital instructions and guidelines for external suppliers, integrated with order requests to ensure materials arrive in the right place at the right time.

3. Enforce continuous improvement. Utilize additional data to further refine processes. If issues persist (e.g., lead times remain high despite digital navigation), investigate further. For instance, an overworked employee may struggle to reallocate inbound materials or notify ordering departments on time.

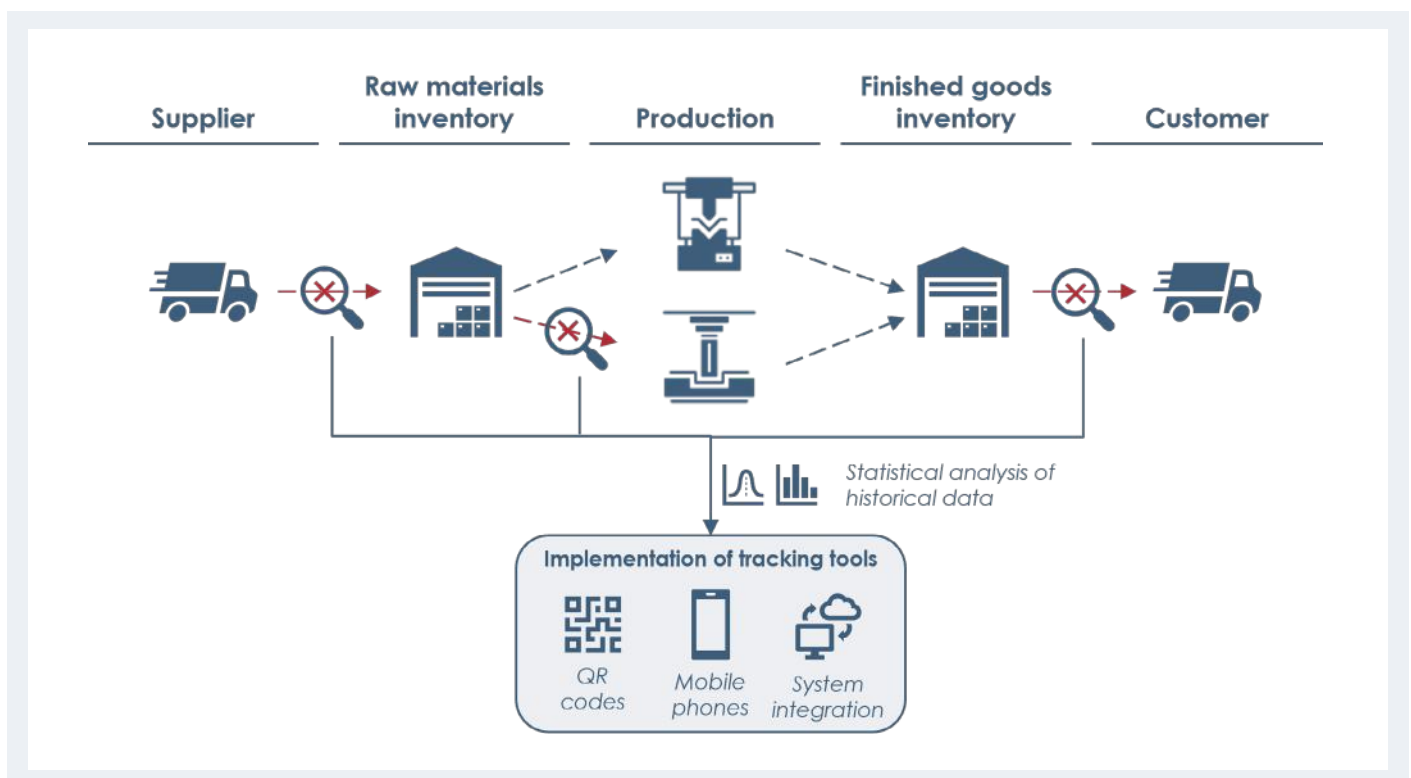


Figure 7: Data-driven investigation

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Authors



Patrick Kabasci

Executive Director
Digital Transformation
patrick.kabasci@innovation-center.com



Pavel Gorbachev

Senior Innovation Specialist
Industry 4.0
pavel.gorbachev@innovation-center.com



Jannik Herding

Innovation Manager
Industry 4.0
jannik.herding@innovation-center.com

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We help you map critical processes to identify inefficiencies, such as media breaks and missing data.



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